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WATER RETENTION OF GRANITIC SOILS IN THE IDAHO BATHOLITH

James L. Clayton and Chester E. Jensen

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James L. Clayton and Chester E. Jensen

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U. S. Department of Agriculture
Ogden, Utah 84401
Robert W. Harris, Director

THE AUTHORS

JAMES L. CLAYTON has served as Research Soil Scientist with the Intermountain Station since 1967. He received his B.S. and M.S. degrees in soil science from the University of California at Berkeley.

CHESTER E. JENSEN is Principal Statistician for the Intermountain Forest and Range Experiment Station. Previously, he held the same position at the Northeastern and Central States Forest Experiment Stations. Mr. Jensen, who holds a master of forestry degree from Michigan State University, received his training in graduate statistics at Iowa State University.

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ABSTRACT

Volumetric water retention at 1/3 and 15 bars was evaluated for strength of relation to the interacting effects of percent organic matter, percent fines (<50μm diameter) and soil bulk density. Samples used in the models were restricted to soils formed from granitic parent materials from the Idaho Batholith.

These soils are unique in that they are coarse-textured and have a broad range of organic matter content. Where a broad range of textures exists, texture (aside from pore size distribution) has often been found to be the single variable most useful in predicting retention. Perhaps by reason of its more limited range (particularly in the clay fraction), texture appeared to have only a secondary effect in the Batholith soils. In contrast, retention was strongly affected by organic matter in the coarse-textured soils here, possibly because of the broad organic matter range and the enhanced potential for organic matter to exert its retention effects. Organic matter alone explains 57 percent of the variance in water retention at 1/3 bar, and 62 percent at 15 bars tension. Incorporating the interacting effects of the remaining two variables explains an additional 17 percent of the variance in water retention at 1/3 bar, and an additional 11 percent at 15 bars.

Tables and equations for the two retention models are presented in the Appendix. The final models were subsequently adjusted by least squares to two new data sets of geographically diverse soils from the Idaho Batholith. The adjusted retention models operate well for predicting water retention at both energy levels. The value of the models is discussed in light of these findings.

INTRODUCTION

Knowledge of the water retention properties of soils is an important facet of the hydrologic data necessary for wise management of forested lands. Management decisions that are based on soil water retention data include: types and expected rates of timber regeneration; potential for erosion and sediment production; changes in water yields following vegetative manipulation; design and location of roads; and a myriad of ecological factors.

Land managers have become increasingly aware of the importance of hydrologic inputs to forest land management in the Idaho Batholith in the last decade as a result of the contrasting values of a timber resource, fishery resource, and the inherent high erosion potential of the Batholith soils (Bethlahmy and Kidd 1966; Gonsior and Gardner 1971; Haupt and Kidd 1965; Megahan and Kidd 1972a and 1972b).

We have attempted in this study to provide a more complete understanding of the interacting effects of percent soil organic matter (OM), bulk density (ρb), and percent fines (diameter <50μm, F) on water retention. The water retention models developed appear to have regional applicability throughout the Idaho Batholith.

The prediction of soil water storage has practical value only when either the parameters used for this prediction are more easily determined than water retention determined by conventional laboratory techniques, or the soil parameters other than water retention are available. Experienced field soil scientists can make reasonably accurate estimates of texture, organic matter content, and bulk density (Visser 1966), particularly after some training and familiarity with the soils involved.

The coarse nature of the soils (textures are predominantly loamy coarse sands or coarse sandy loams), and the relatively high organic matter content appear to preclude use of existing methods of estimating soil water storage (Smith 1944; Shockley 1955; Broadfoot and Burke 1958; Carlson and others 1956; Stone and Garrison 1940). For this reason another approach to water retention prediction seemed desirable for Batholith soils.

The two energy levels for water retention used in developing the retention models were chosen somewhat arbitrarily. Retention at 15 bars is frequently used as an estimation of the permanent wilting point of a soil. This concept probably has little value in the Batholith except for grasses and forbs. The roots of many shrubs and trees follow fracture lines or penetrate the matrix of highly weathered bedrock and can be found at great depths (40 to 50 feet); presumably they obtain water at these depths after the overlying "soil" has reached the actual wilting point for the species involved. However, the retention at 15 bars is useful and necessary in classifying the moisture regime of soils as specified by the National Cooperative Soil Survey (1970).

Retention at 1/3 bar has been used frequently for estimating field capacity. In coarse-textured soils, 1/3 bar is usually considered too high an energy level of water retention (too low a water volume) for this estimation. However, there is no unanimity of opinion among soil scientists as to a better figure; 0.10 bar, 0.061 bar (60 cm.), and 0.05 bar water tension have all been proposed, and can be found in the existing literature. Petersen and others (1971) support utilizing 1/3 bar measurements, at least until some other value on the moisture characteristic curve becomes widely utilized. Because of the widespread use of 1/3 bar, the authors concur. The primary intent of this paper is to develop models relating retention to OM, F, and ρb at two commonly used energy levels.

Because of the rooting nature of plants growing in the Idaho Batholith, the authors make no implication that the difference between 15 bars and 1/3 bar is the available water.

METHODS

Forty-seven soil samples were collected for laboratory analysis from 28 sites in the southwestern portion of the Idaho Batholith in seven forested experimental watersheds, that are tributaries of the Middle Fork of the Payette River. Elevations range from 1,200 to 2,200 m. on these watersheds, and a large variety of soil families, typical of the southern Batholith, can be sampled here. Great Soil Groups include both Lithic and Entic Cryoborolls and Cryopsamments, and Typic Cryorthents. Families are generally shallow, sandy-skeletal, mixed or coarse-loamy mixed. A-C profiles over weathered quartz monzonite bedrock predominate.

The 47 soil samples used in deriving the original models include A11, A12, AC, and C horizons. No B horizons were present at the 28 sampling sites. Samples were oven-dried at 105° C. and then put through a 2-mm. sieve. Textures were run on the less than 2 mm. fraction by the hydrometer method of Day (1965). Percent fines (silt plus clay) is presented as percent by weight of the <2 mm. fraction. Organic matter analyses were made in a carbon combustion furnace in an oxygen stream, and determined by weight loss. Although this method overestimates organic matter (OM) slightly by dehydration of clays it was found to be more reproducible than wet oxidation methods, probably because of the coarse nature of organic material in the surface horizons. Bulk density samples were taken in the field by use of a 5.71 cm. diameter soil core sampler. Water retention at 15 bars was run on a pressure membrane apparatus, and at 1/3 bar in a porous-plate pressure device. Samples run were from the <2 mm. fraction. Results are expressed on a percent by volume basis. Experience has shown that no attempt at repacking these loose, weakly aggregated soils best simulates the original bulk density (personal communication with Delon Hampton, Howard Univ. 1971). The change in pore size distribution might be quite drastic using disturbed samples, so we attempted pressure plate analyses of water retention on undisturbed core samples. However, reproducibility was poor, probably because of inadequate contact between the soil and pressure plate. For this reason, we resorted to the use of disturbed samples. This objection is probably small at 15 bars because most water is held by adsorption on particle surfaces. This may be the case for much of the water at 1/3 bar in very coarse soils.

The soil information thus derived for the samples was then subjected to analysis. Preliminary scanning of alternative two- to four-dimensional data plots resulted in the isolation of three independent variables deemed worthy of inclusion in the final models: percent organic matter, percent fines (F) which is equivalent to 100 minus the percent sand, and bulk density (ρb).

Expectation and Data Trends

Expected curves for water retention represent our attempts at describing the theoretical relationships between water retention and independent variables, the latter being allowed to vary within prescribed limits. These curves are presented here (figs. 1, 2, and 3) for the three independent variables included in the final models.

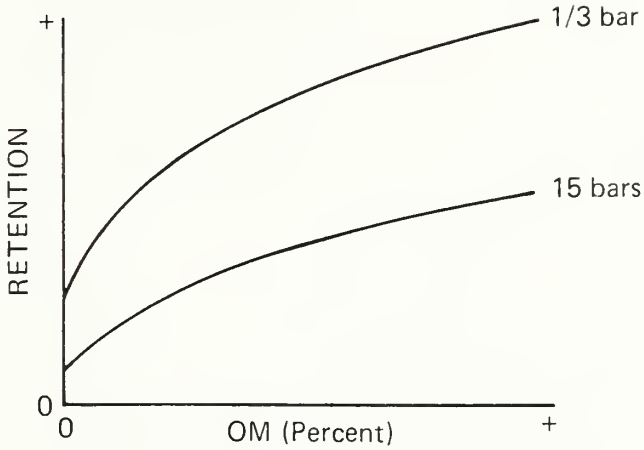


Figure 1.--Expectation for water retention as a function of percent OM.

Our initial expectation was for a linear increase in retention with increasing OM values; however, the data strongly indicated the diminishing increase in retention with increasing OM as shown in figure 1. The curvilinear relation has a positive intercept at OM = 0; this value is equal to the matric potential of a polydispersed system of lithic particles having a pore size distribution that would hypothetically be formed for a coarse-textured mineral soil. The amount of increase in water retention diminishes as OM increases, particularly beyond about 8 percent OM. A possible explanation is that initial increments of OM tend to coat coarse lithic particles and the interstices of large pores, maintaining the single grain structure and not altering pore size distribution. However, at higher OM levels, added increments of OM tend to bind the coarse particles forming a weak crumb structure (Emerson 1959). This would change the pore size distribution, and could result in a higher percentage of large pores. This effect on retention should be more evident at the lower energy level (1/3 bar) since most retention at 15 bars is by adsorptive (surface active) phenomena. Again the data support this. The retention at 15 bars over OM is more nearly linear than it is at 1/3 bar tension.

The expectation for water retention as a function of percent fines (F) (fig. 2) follows essentially the same line of reasoning as retention over OM (fig. 1). Again there is a positive intercept at F = 0, equal to the matric potential of a polydispersed soil in which all particles are greater than 50μm in diameter. Initial increments of

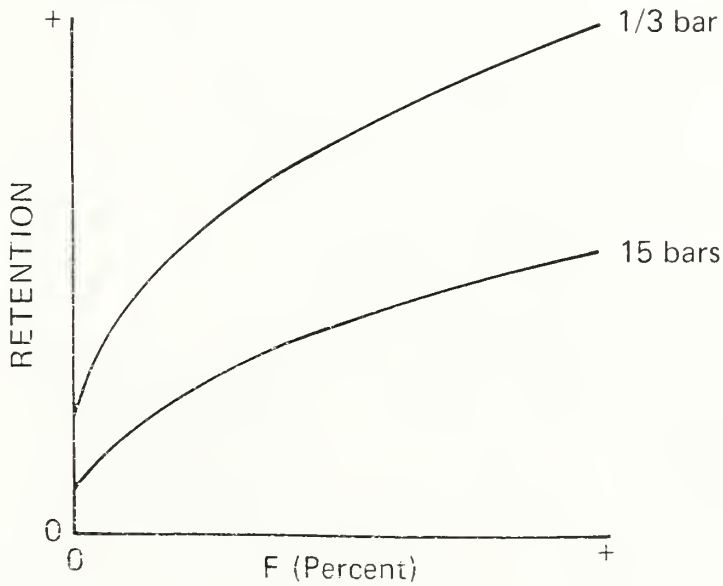
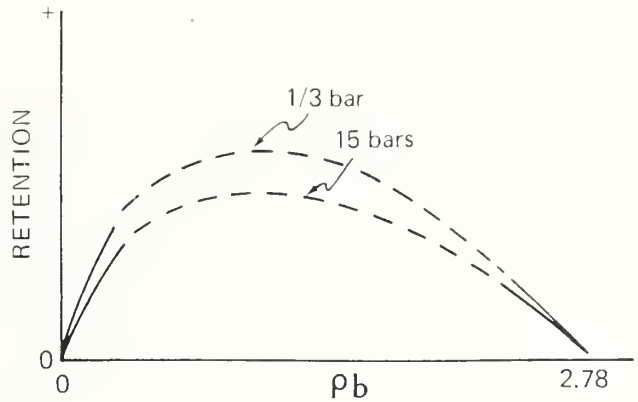


Figure 2.--Expectation for water retention as a function of percent F.

Figure 3.--Expectation for water retention as a function of ρb.



fine particles occupy large pores, increase the specific surface (and consequently bulk density) and tend to form smaller pores at higher F-levels. Added increments of fines begin to favor a weak crumb structure due to interparticle binding, formation of larger pores, and a decrease in bulk density. The data suggest this phenomenon has a strong effect in the range F = 20 to 30 percent by weight.

The expectation for retention over bulk density (ρb) poses an interesting problem. Logically, at ρb = 0 and ρb = ρS (where ρS is solid phase density; approximately 2.78 for our parent materials), porosity and therefore retention is 0. Retention therefore has two minima and is assumed to have one maximum at some intermediate value (fig. 3). The value of ρb where this assumed maximum occurs is a function of the pore size distribution in a polydispersed soil system. The total porosity, E, approaches a maximum where ρb approaches zero, but this sheds no light on maximum retention at energy levels (tensions) greater than zero (where zero is saturation percentage). The increase in retention from very low ρb values to this maximum is probably attributable to increased specific surface. Interparticle binding by OM or F to form a weak crumb structure diminishes this effect, as previously pointed out.

Changes in the foregoing main effects were expected to occur as the three soil factors interacted and the combined expectation would be as shown in figure 4. Actual data points would be distributed over the ranges of the soil factors in a pattern

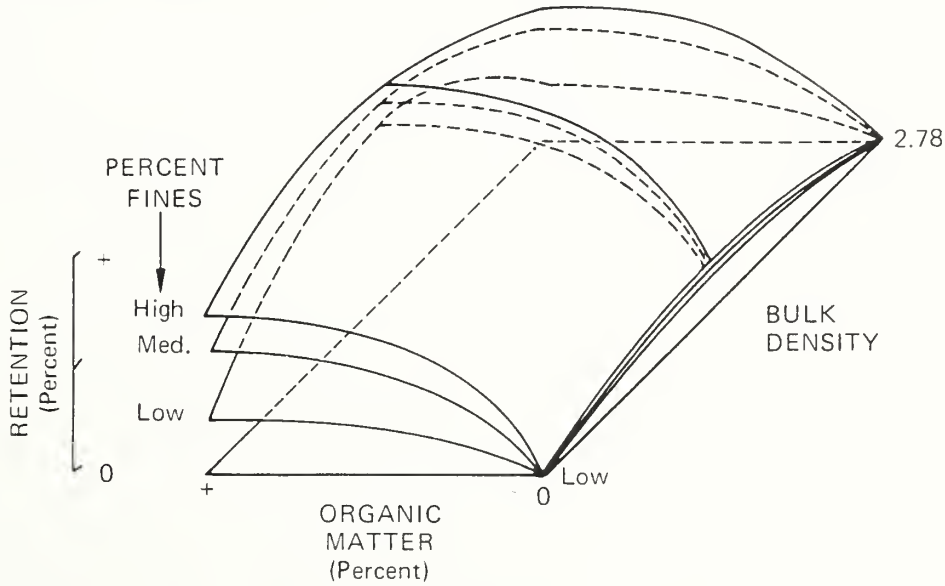


Figure 4.--Expected relations between water retention, organic matter, bulk density, and percent fines.

roughly dictated by the correlations between them. Soils with high ρb, F, and OM, for example, would not occur. Extension of expectation over these areas is simply a sacrifice to ease of graphic display. A tendency toward convergence of surfaces for all levels of percent fines (F) was expected to occur with decreasing organic matter (OM). With increasing OM and when approaching extremes of bulk density (ρb), the suppressive effects of decreasing F on retention were expected to be accentuated.

Model Development

The position of the data array in the expected model and a more precise estimate of the nature of the interaction was next ascertained. Expected retention trends over OM were fitted to the plotted data points by approximate least deviations (for both 1/3 and 15 bars), for two or three F-strata, within each of three ρb-strata (see fig. 5).

It was apparent from these data trends that the data lay in the right front quarter of the expected surfaces and were fairly well distributed over low to medium F with only a few high F-values being present. Furthermore, the expected interactions appeared to exist; thus, our next effort was directed at generating a suitably accurate interaction descriptor. Using such a model, we hoped to minimize curve form bias likely to be associated with the application of less sensitive transformations.

The curves over OM were characterized using algebraic forms identified with Matchacurves-1 and -2 (Jensen and Homeyer 1970 and 1971). Differences in these functions (intercepts, maxima, and degree of curvature), smoothed in accord with expectation, were then expressed as appropriate Matchacurve functions of ρb and F to arrive at an algebraic approximation of the four-dimensional relation. And finally, the algebraic function was refitted to the original data points by least squares, using a simple linear model having zero intercept.

The complexity of the final descriptors probably will appear objectionable in our old frame of reference where the lack of available computers necessitated descriptor simplicity. This is no longer true, and where complex algebra was required to describe particular main effects and interactions in the model here, we were not reluctant to use it. The descriptors herein were developed over a period of 1 week and final scaling passes in the computer were extremely short and inexpensive.

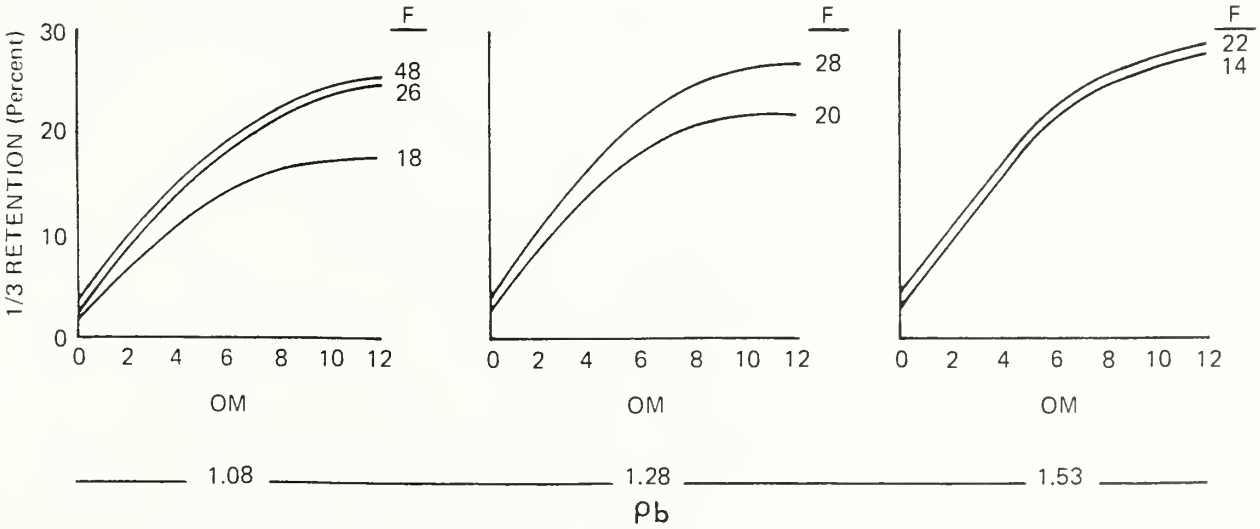


Figure 5.--Expected trends fitted to the data.

RESULTS

Description of the Models

Evaluations of the dependent and independent variables show the means, standard deviations, and ranges for the data used in developing the two water retention models (table 1). The water retention values appear typical for coarse-textured soils. Values published by Broadfoot and Burke (1958, p. 5) can be compared by dividing Batholith soil values by the mean ρb value to express retention on a weight basis. The retentions at both energy levels fall between their published values for loamy sand and sandy loam textures. A similar comparison of bulk densities by textural classes can be made with Broadfoot and Burke's data (1958, p. 13) and shows our bulk densities to be similar.

The water retention surfaces incorporating the effects of all independent variables for 1/3 bar and 15 bars tension are presented in figures 6 and 7, along with the indices of determination (R^2), and the standard errors of estimate ($s_{y \cdot x}$). The equations for these models are specified in the Appendix.

Basically these surfaces fit expectation and can be described as follows:

The most significant feature of the 1/3-bar model is that retention increases strongly (15 to 20 percent) as OM increases from 0 to 8 or 10 percent, regardless of ρb and F values. At low OM, only small to modest positive effects can be seen over ρb and F. And, at high OM, the expected interaction materializes except that the left front third of the figure has been arbitrarily brought to a lower asymptote for each F-level. Data are either scant or absent there. A sharp retention increase in the range $1.3 < \rho b < 1.5$ occurs in the lower range of F, 10 to 20 percent.

Table 1. *Univariate descriptions of the data. (N = 47 for all variables)*

Item	Mean	Standard deviation	Lowest	Highest	Range
1/3 atm. Pv	15.11	4.14	6.5	27.0	20.5
15 atm. Pv	6.20	1.73	3.7	11.1	7.4
% OM	4.26	1.97	1.6	11.7	10.1
% F	22.80	8.46	7.4	53.0	45.6
Bulk density g/cc	1.30	.19	.94	1.7	.76

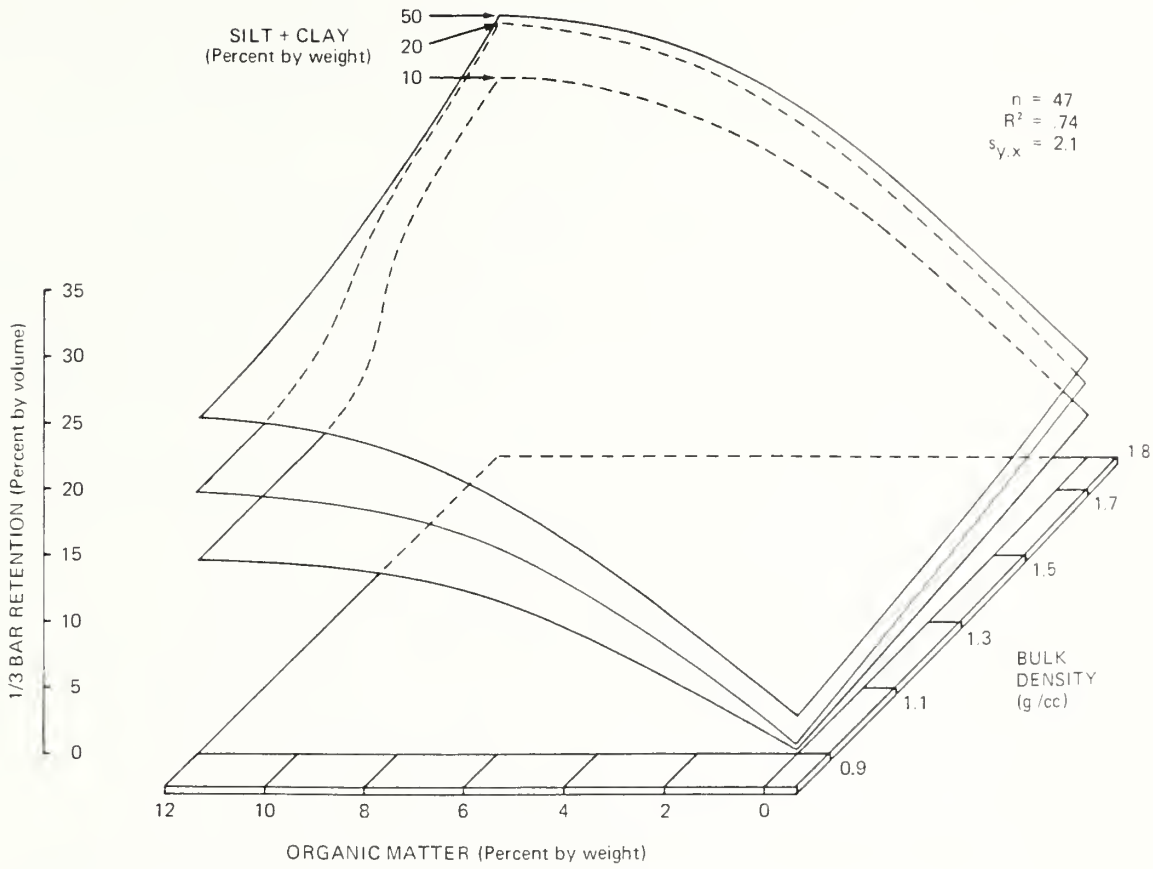


Figure 6.--Water retention at 1/3 bar as a function of percent OM, percent F, and ρb.

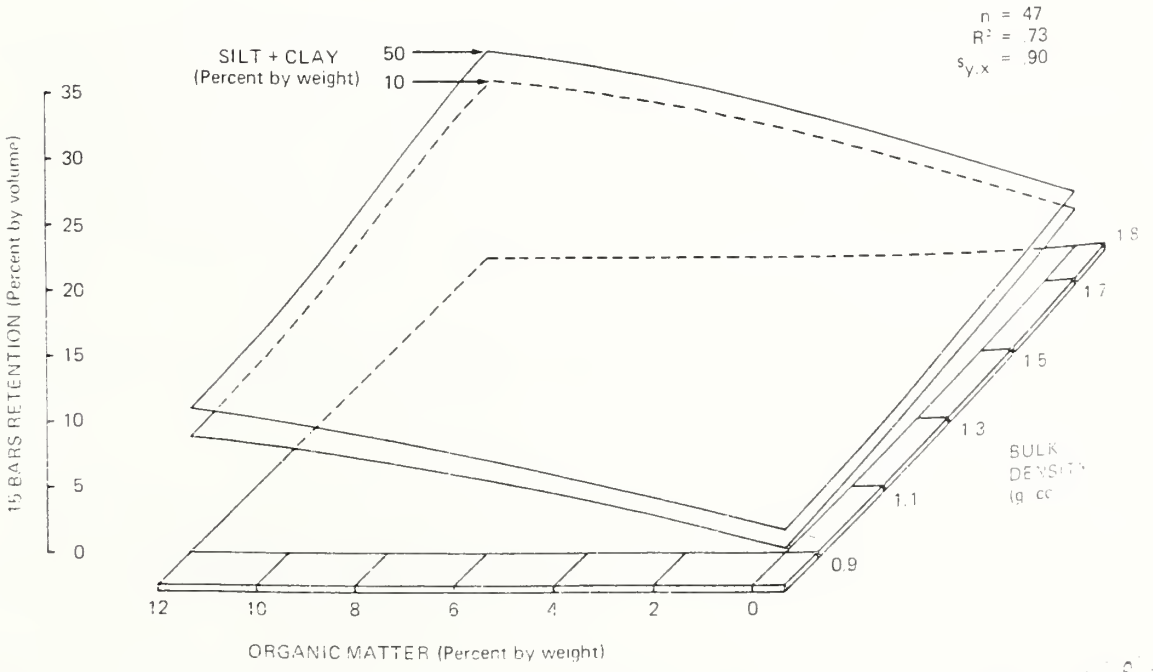


Figure 7.--Water retention at 15 bars as a function of percent OM, percent F, and ρb.

There are areas on the surface of figures 6 and 7 showing retention values that are logically impossible, and there are areas wherein there are no real data values. An example is the point on the high F surface of the 1/3 bar model where OM = 12 and ρb = 1.8. The predicted retention is approximately 33 percent by volume. This is approximately the volume of the total pore space. We do not want to promote the concept that saturation percent is equal to 1/3 bar percent for the above array of independent variables. The tables presented in the Appendix show dashed lines instead of retention values where the model is not deemed applicable.

Basically, the same responses in water retention at 1/3 bar are found at 15 bars tension. One major difference is the lack of sharp change in retention in the middle of the ρb range for high OM values and low F values. This indicates that the distinct change at these values noted in the 1/3 bar model may be due to a structural binding of lithic and organic particles to form voids that drain at tensions greater than 1/3 bar, but less than 15 bars. This effect is diminished as percent F increases in the 15 bar model. This may indicate that higher fines either mask the effect, or change the structural interaction of OM and lithic material.

At 15 bars tension, organic matter is again the independent variable that most influences water retention. At all OM levels, retention increases with increasing values of both ρb and F.

Model Performance

The two retention models were developed from soil samples of a very localized area within the Batholith. How applicable these models might have been to alternative areas was unknown, but some insight was provided by an evaluation of model performance for two additional sets of soil samples from new and geographically diverse areas of the Batholith. Univariate data descriptions for the new data sets appear in tables 2 and 3.

Evaluation of the scale and form of the original models was made possible by first adjusting these models to the new data sets by least squares, in a simple linear model forced through the origin: adjusted retention = b (model retention, M); Y_i = new retention values; and, $b = \Sigma M_i Y_i / \Sigma M_i^2$.

The b-value simply shrinks or stretches the original model to fit the new data set without changing the specified form and provides a basis for judging adequacy of the original model scale. A b-value of 1.000 represents a perfect scaling match between model and data set and as may be seen in table 4, the b's ranged from 0.909 to 1.065 for the new data sets; i.e., the original model scales ranged from about 9-percent high to 6-percent low. In a larger array of check data sets, we might reasonably expect an even larger range of corrections, perhaps ±15 percent. Users of prediction tables 5 and 6, Appendix, should be aware of the magnitude of this potential scaling error for the *unadjusted* models, but users should also realize that the models can be *adjusted* to soil data for any[1] area as they were above for the check data sets, thus removing scaling bias of the models for new areas.

Some idea of the applicability of the *interaction form* for the new data sets is provided by an evaluation of departures of actual retention values from the corresponding ones given by the models adjusted to each new data set (fig. 8, table 4).

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[1]Again, the authors advise that application of the original models be limited to areas having similar soils and due consideration be given to the need for scaling to the new soils (p. 9, par. 7). Extrapolation to soils having widely differing physical properties should only be attempted after laboratory confirmation of both the form and scale of the models.

Table 2.--*Univariate data descriptions for new data set 1; N = 24 at 15 bars, N = 21 at 1/3 bar*

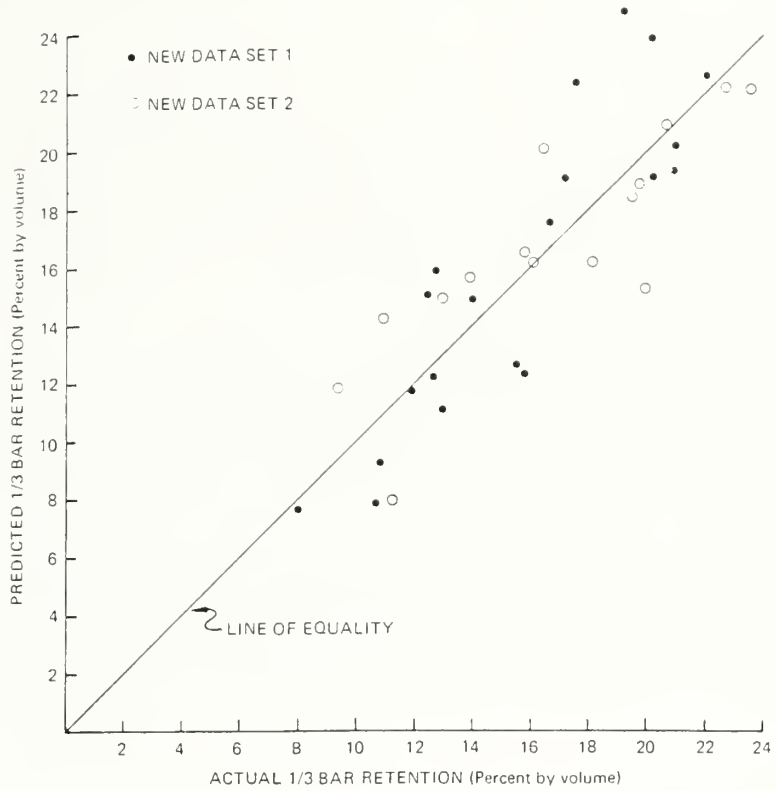
Item	Mean N = 24	Mean N = 21	Standard deviation N = 24	Standard deviation N = 21	Lowest	Highest	Range
1/3 bar	--	16.00	--	4.30	8.0	25.2	17.2
15 bars	6.70	--	2.07	--	3.2	9.9	6.7
% OM	4.17	4.44	1.86	1.82	1.6	8.6	7.0
% F	19.97	21.30	6.85	7.64	10.0	36.7	26.7
ρb	1.34	1.38	.15	.15	1.13	1.73	.60

Table 3.--*Univariate data descriptions for new data set 2; N = 15*

Item	Mean	Standard Deviation	Lowest	Highest	Range
1/3 bar	16.71	4.38	9.4	23.6	14.2
15 bars	6.65	2.12	3.1	11.2	8.1
% OM	5.00	2.21	1.3	9.3	8.0
% F	34.10	9.76	23.0	55.0	32.0
ρb	1.34	.21	.93	1.59	.66

Table 4.--*Comparison of water retention values at both energy levels for the original models and the two new data sets*

Retention bars	Data set	n	Average retention	b	Adjusted model $S_{y \cdot x}$	Adjusted model R^2
1/3	Orig.	47	15.1	0.984	2.1	.74
	1	21	16.0	1.001	2.7	.66
	2	15	16.7	.909	2.4	.71
15	Orig.	47	6.2	.982	.9	.73
	1	24	6.7	1.065	1.1	.72
	2	15	6.7	.911	1.2	.70



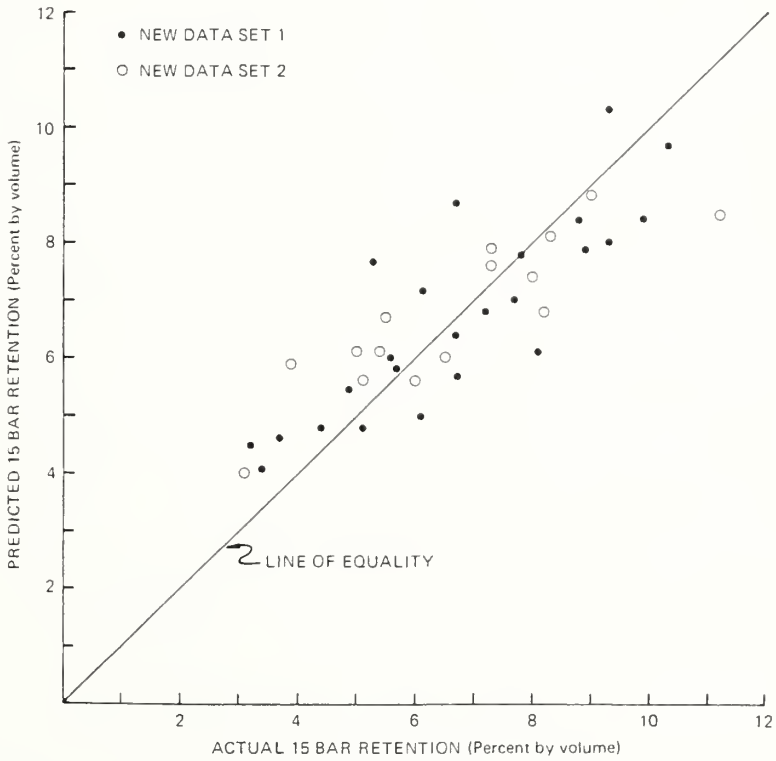


Figure 8.--Plots of predicted values after least squares adjustment vs. actual values for the two new data sets. (The line with 0 intercept and slope of 1 equals 1 to 1 correspondence.)

Visual appraisal of *all* departures shown in figure 8, one-third retention, suggests that the *form* of the original model is especially appropriate in the midrange of actual retention. At the lower extreme, average negative bias in estimated retention maximizes at perhaps 1 percent and average positive bias at 1.5 percent at the upper extreme. So the original model, scaled to the data set from each of two new areas, performed reasonably well when evaluated *jointly* for these applications.

This limited check, at least, shows some promise of the model *form* being applicable for Batholith soils in general. Additional support for this thesis is present in table 4 where the $s_{y.x}$ (standard errors of estimate) are fairly consistent. Note that $s_{y.x} = 2.1$ for the original model is apt to be an underestimate since only two degrees of freedom were charged against the fitting process. Actually an unknown number of degrees of freedom were sacrificed in graphically exhausting the original data set of information.

Applying the same evaluation as above to the 15-bar retention model, an average positive bias of about 1 percent in estimated retention exists at the lower extreme of actual retention, an average of a negative 1 percent at the upper extreme. Although the magnitudes of bias do not seem critical to conventional field applications, the form of the original model seems consistently different for the two new data sets.

CONCLUSIONS

Models developed for predicting water retention at 1/3 and 15 bars tension demonstrate the strong influence of organic matter on water retention in coarse-textured soils of the Idaho Batholith. The models were developed using data from disturbed soil samples, a problem that could not be overcome due to lack of cohesive strength of the soils. At 1/3 bar, the adverse effects of the disturbed soils on retention measurements should be somewhat tempered by the weak structure inherent in the field soils. At 15 bars, almost all water is retained by adsorption, negating the problem of soil sample disturbance.

The original models were developed with the constraint that they fit theoretical expectations over the ranges sampled for the three independent variables: percent by weight organic matter, percent by weight fines (<50μm diameter), and bulk density.

Two new data sets with wide geographic variability within the Idaho Batholith were used to test the applicability of the original models. Both sets confirmed the general curve form, and the original model performed reasonably well after least squares adjustment. The second new data set included three soils formed from loess having bulk densities and textures at the limits of the original data used in developing the models. Predicted retention values at both energy values were surprisingly accurate for all three loessal soils.

For several reasons, the authors urge caution in the use of the models for predicting hydrologic and ecologic factors such as water yield and "available soil moisture." Experience in the Batholith has shown that the bedrock is generally highly fractured and often highly weathered to great depths. Deep water storage and utilization of this water by deep rooted plants is universal throughout the Batholith. Drill cores recovered from depths of 800 feet have shown hydrolysis of biotites and iron oxide stains coating mineral grains (unpublished data on file, Intermountain Station, Boise, Idaho). Secondly, the effects of disturbance on the soils disrupted the natural pore size distribution due to soil structure, which almost certainly affected the values determined at 1/3 bar tension. Because of the coarse nature and inherent single grain structure of the Batholith soils, this effect may be minimal, especially at low organic matter and low fines percentages.

The models do have value in estimating soil water regimes necessary in classifying soils at the family level. In addition, they give some estimate of soil water retention in the soil at two energy levels, and have practical value in estimating moisture regimes for revegetation efforts.

Because the regression models were interaction-sensitive, they allowed exhaustion of information from the independent variables within the constraints of theoretical expectation. Modest curve form bias and the close proximity of the standard errors of estimate for the interaction models fitted to the original and to two new data sets, tend to substantiate the general applicability of the original interaction forms. It would, however, probably be advisable to regard the original model forms developed here as applicable on an interim basis, to be improved upon as more data become available.

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APPENDIX

Table 5. *Tables for predicting volumetric water retention at 1/3 bar*

(A) 10% F

ρb	% OM 0	2	4	6	8	10	12
0.9	--	--	8.55	11.6	13.5	14.4	--
1.0	--	4.57	8.60	11.6	13.5	14.4	--
1.1	.66	4.89	8.80	11.8	13.6	14.4	--
1.2	1.04	5.56	9.56*[1]	12.4	13.9	14.6	--
1.3	1.36	5.85	9.80	12.5	--	--	--
1.4	1.64	5.92*	9.92**	13.0	--	--	--
1.5	1.95	7.60**	13.1	17.7	--	--	--
1.6	2.52	8.76	14.9	--	--	--	--
1.7	2.95	9.40	15.7	--	--	--	--
1.8	--	--	--	--	--	--	--

(B) 20% F

ρb	% OM 0	2	4	6	8	10	12
0.9	--	--	11.6	15.6	18.1	19.4	19.8
1.0	--	6.68	11.8	15.7*	18.2	19.4	19.8
1.1	1.90	7.21	12.2*	16.0**	18.4	19.6	20.0
1.2	2.36	8.28*	13.6*	17.3	19.3	20.2	20.5
1.3	2.83	9.28**	15.0***	18.9	21.0	21.9	22.1*
1.4	3.27	9.85***	16.0*	20.7	23.7	--	--
1.5	3.77	10.5 *	16.6***	21.8	--	--	--
1.6	4.61	11.2 *	17.7*	23.0*	--	--	--
1.7	5.25	12.1	18.8**	24.3	--	--	--
1.8	5.69	12.9	19.9	--	--	--	--

(C) 30% F

ρb	% OM 0	2	4	6	8	10	12
0.9	--	--	13.8	18.7	22.2	24.2	25.1
1.0	--	--	14.1	18.9	22.3	24.3	25.2
1.1	3.06	8.83	14.5*	19.3**	22.6	24.6	25.4
1.2	3.46	9.96*	16.1**	20.8**	23.9	25.4*	26.0
1.3	3.97	10.7 *	17.0**	21.8	24.8	26.2	--
1.4	4.47	11.0	17.1	22.1	25.3	27.0	--
1.5	5.04	11.3	17.4*	22.5	--	--	--
1.6	5.82	12.2	18.5	23.6	--	--	--
1.7	6.46	13.1	--	--	--	--	--
1.8	6.98	13.9	--	--	--	--	--

(D) 40% F[2]

ρb	% OM 0	2	4	6	8	10	12
0.9	--	--	14.3*	19.1	22.5	24.5	25.4
1.0	--	--	14.6*	19.3	22.7	24.6	25.5
1.1	--	9.33	14.9*	19.6	23.0	24.9	25.7
1.2	4.06	10.5	16.5	21.2	24.2	25.7	26.3
1.3	4.57	11.2	17.4	22.1	25.0	26.4	--
1.4	5.10	11.4	17.5	22.3	25.4	27.1	--
1.5	5.65	11.8	17.7	22.6	--	--	--
1.6	6.28	12.6	18.7	23.7	--	--	--
1.7	6.86	13.4	--	--	--	--	--
1.8	7.41	14.3	--	--	--	--	--

[1]Asterisks denote data points.
[2]For fines >40% use this table. The authors do not advise use of the model for fines >55%.

Table 6. *Tables for predicting volumetric water retention at 15 bars*

(A) 10% F

ρb	% OM 0	2	4	6	8	10	12
0.9	--	--	4.08	5.60	6.90	7.97	--
1.0	--	2.51	4.22	5.73	7.03	8.09	--
1.1	.82	2.72	4.44	5.95	7.24	8.30	--
1.2	1.07	3.00	4.74*[1]	6.27	7.58	8.65	--
1.3	1.36	3.35	5.14	6.72	--	--	--
1.4	1.69	3.79*	5.66**	7.31	--	--	--
1.5	2.04	4.30**	6.31	8.07	--	--	--
1.6	2.39	4.86	7.03	--	--	--	--
1.7	2.70	5.30	7.57	--	--	--	--
1.8	--	--	--	--	--	--	--

(B) 20% F

ρb	% OM 0	2	4	6	8	10	12
0.9	--	--	4.66	6.26	7.66	8.85	9.80
1.0	--	3.05	4.81	6.40*	7.79	8.98	9.91
1.1	1.34	3.26	5.02*	6.61**	8.01	9.19	10.1
1.2	1.60	3.54*	5.32*	6.93	8.34	9.54	10.5
1.3	1.89	3.89**	5.72***	7.37	8.82	10.1	11.0*
1.4	2.22	4.32***	6.23*	7.96	--	--	--
1.5	2.57	4.83*	6.88***	8.71	--	--	--
1.6	2.92	5.39*	7.60*	9.54*	--	--	--
1.7	3.23	5.84	8.15**	10.2	--	--	--
1.8	3.41	6.04	8.37	--	--	--	--

(C) 30% F

ρb	% OM 0	2	4	6	8	10	12
0.9	--	--	5.27	6.93	8.40	9.67	10.7
1.0	--	--	5.42	7.07	8.53	9.79	10.8
1.1	1.87	3.83	5.64*	7.28**	8.75	10.0	11.0
1.2	2.13	4.11*	5.93**	7.60**	9.08	10.4*	11.4
1.3	2.42	4.45*	6.33**	8.04	9.56	10.9	--
1.4	2.75	4.88	6.84	8.62	10.2	11.6	--
1.5	3.10	5.39	7.49*	9.38	--	--	--
1.6	3.45	5.95	8.22	10.2	--	--	--
1.7	3.76	6.40	--	--	--	--	--
1.8	3.94	6.61	--	--	--	--	--

(D) 40% F[2]

ρb	% OM 0	2	4	6	8	10	12
0.9	--	--	5.46*	7.12	8.60	9.89	10.9
1.0	--	--	5.61*	7.26	8.74	10.0	11.1
1.1	--	4.02	5.83*	7.47	8.95	10.2	11.3
1.2	2.33	4.30	6.12	7.79	9.28	10.6	11.6
1.3	2.63	4.65	6.52	8.23	9.76	11.1	--
1.4	2.96	5.07	7.02	8.81	10.4	11.8	--
1.5	3.31	5.59	7.68	9.57	--	--	--
1.6	3.65	6.15	8.40	10.41	--	--	--
1.7	3.96	6.59	--	--	--	--	--
1.8	4.15	6.80	--	--	--	--	--

[1]Asterisks denote data points.

[2]For fines >40% use this table. The authors do not advise use of the model for fines >55%.

$\hat{Y}$ = 1/3 bar retention = f (%OM, %F, ρb)

$$(1) \quad \hat{Y} = \left\{ LEDG + (REDG - LEDG) \left\{ \frac{e^{-\left|\frac{\frac{OM}{15} - 1}{1 - I}\right|^{N}} - e^{-\left|\frac{1}{1 - I}\right|^{N}}}{1 - e^{-\left|\frac{1}{1 - I}\right|^{N}}} \right\} \right\}^{0.984}$$

$$(2) \quad REDG = 15 + (RR - 15) \left\{ \frac{e^{-\left|\frac{\frac{F}{55} - 1}{1 - RI}\right|^{10}} - e^{-\left|\frac{1}{1 - RI}\right|^{10}}}{1 - e^{-\left|\frac{1}{1 - RI}\right|^{10}}} \right\}$$

$$RR = 26 + 9.9812\ (\rho b - 0.9)^{2.1}$$

$$RI = 0.05 + 0.295\ e^{-\left|\frac{\frac{(1.8 - \rho b)}{0.9} - 1}{0.63}\right|^{6.8}}$$

$$(3) \quad LEDG = LR \left\{ \frac{e^{-\left|\frac{\frac{F}{55} - 1}{1 - LI}\right|^{LN}} - e^{-\left|\frac{1}{1 - LI}\right|^{LN}}}{1 - e^{-\left|\frac{1}{1 - LI}\right|^{LN}}} \right\}$$

$$LR = 2.9 + 5.278\ (\rho b - 0.9)^{1.1}$$

$$LI = 0.4017\ e^{-\left|\frac{\frac{\rho b}{0.9} - 1}{0.39}\right|^{1.8}} - 0.0017$$

$$LN = 4 - e^{-\left|\frac{\frac{\rho b}{1.34} - 1}{0.1865}\right|^{4.6}}$$

(4) $$N = NREDG + NYP \left\{ \frac{e^{-\left|\frac{\frac{(55 - F)}{55} - 1}{1 - NSI}\right|^{20}} - e^{-\left|\frac{1}{1 - NSI}\right|^{20}}}{1 - e^{-\left|\frac{1}{1 - NSI}\right|^{20}}} \right\} - NSUB$$

$$NREDG = 3.3 + 0.45\, e^{-\left|\frac{\frac{\rho b}{1.28} - 1}{0.1}\right|^{4}}$$

$$NSI = 0.53 + 0.07\, e^{-\left|\frac{\frac{(1.8 - \rho b)}{0.9} - 1}{0.35}\right|^{10}}$$

$$NYP = 0.5 + 0.05\, e^{-\left|\frac{\frac{(\rho b - 0.9)}{0.9} - 1}{0.7}\right|^{20}} - 0.55\, e^{-\left|\frac{\frac{(\rho b - 0.9)}{0.785} - 1}{0.4}\right|^{8}}$$

$$NSUB = 0.1 \left\{ e^{-\left|\frac{\frac{(1.8 - \rho b)}{0.9} - 1}{0.35}\right|^{10}} \right\} \left\{ e^{-\left|\frac{\frac{F}{32.5} - 1}{0.38}\right|^{10}} \right\}$$

(5) $I = 0.01$

NOTE: $0 \le OM \le 15\%$
$0.9 \le \rho b \le 1.8$
$0 \le F \le 55\%$

$\hat{Y}$ = 15 bar retention = f (%OM, %F, ρb)

(1) $$\hat{Y} = \left\{ REDG - \left\{ \frac{(REDG - LEDG)}{15^N} \right\} (15 - OM)^N \right\} 0.982$$

(2) $$REDG = RL + 2.9\, e^{-\left|\frac{\frac{F}{55} - 1}{0.7}\right|^5}$$

$$RL = 9.2 + 4.686\, e^{-\left|\frac{\frac{(\rho b - 0.9)}{0.7} - 1}{0.5}\right|^2} - 0.086$$

(3) $$LEDG = LL + 1.478\, e^{-\left|\frac{\frac{F}{55} - 1}{0.682}\right|^{4.3}} - 0.008$$

$$LL = 0.28 + 3.054\, e^{-\left|\frac{\frac{(\rho b - 0.9)}{0.9} - 1}{0.7}\right|^{1.5}} - 0.554$$

(4) $$N = NFLOR + NSIG$$

$$NFLOR = 1.488 + 0.212\, e^{-\left|\frac{\frac{(\rho b - 0.9)}{0.9} - 1}{0.31}\right|^3}$$

$$NSIG = 3.704 \times 10^{-6} (55 - F)^{2.8} + 0.05\, e^{-\left|\frac{\frac{(55 - F)}{47} - 1}{0.16}\right|^2}$$

NOTE: $0 \leq OM \leq 15\%$
$0.9 \leq \rho b \leq 1.8$
$0 \leq F \leq 55\%$

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CLAYTON, JAMES L., and CHESTER E. JENSEN
1973. Water retention of granitic soils in the Idaho Batholith. USDA Forest Serv. Res. Pap. INT-143, 20 p., illus. (Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.)

Volumetric water retention at 1/3 and 15 bars was evaluated for strength of relation to the interacting effects of percent organic matter, percent fines (<50 μm diameter) and soil bulk density for soils from the Idaho Batholith. Organic matter was the strongest of the variables affecting retention in these coarse soils. The final models were adjusted by least squares to two new data sets of geographically diverse soils from the Idaho Batholith. The adjusted retention models operate surprisingly well for predicting water retention at both energy levels.

OXFORD: 114.124:114.1: KEYWORDS: water retention, granitic soils.

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